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Original communication

Estimation of stature by foot length

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Abstract

The aim of this study was to develop a relationship between foot length and stature using linear and curvilinear regression models. Measurements of foot length and stature were taken from 250 medical students (125 males and 125 females) aged 18–30 years. General multiple linear regression model was highly significant ($P < 0.001$) and validated with highest values for the coefficients of determination $R_2 = 0.769$ and multiple correlation coefficient $r = 0.877$. Right foot length, sex and age explained for about 77% variations in stature.

Keywords: Foot length; Stature; Identification; Forensic science; Physical anthropology

1. Introduction

Stature of an individual is one of the vital parts of identification, which is often required in medico-legal practice. Sometimes, fragments of soft tissues are found disposed off in the open, in ditches, or rubbish dumps, etc. and this material is brought to forensic pathologist for examination.[1] The problem of identification mainly arises in these types of cases. There are lots of studies going on for assessing stature, sex, race, etc. from anthropometric measurements of different parts of body for identification purpose.

The present study has been conducted to estimate stature from foot length.

2. Material and method

The study was conducted in the Department of Forensic Medicine and Toxicology, SSR Medical College, Mauritius in the year 2005. The material consisted of 250 young and healthy students (125 males and 125 females) in the age group of 18–30 years. In this study, the sample included only students above the age of 18 years. Above this age, most people attain their maximum growth and therefore attain their maximum foot length.

Height (stature) of the subject was measured in standing posture. The subject was instructed to stand barefooted on the board of a standard stadiometer with both feet in close contact with each other, trunk braced along the vertical board, and head oriented in ear–eye plane by keeping the lateral palpebral commissure and the tip of auricle of the pinna in a horizontal plane parallel to the feet. The measurement was taken in centimeters by bringing the horizontal sliding bar to the vertex.

The foot length was measured as a straight distance between the most posterior projecting point of heel and the most anterior projecting point (the end of great toe or second toe) when placed on flat surface. This measurement excluded any nail extending over the end of the toe.

The entire sample of study, both males and females has been categorized in to three different age groups: under 20 years, 20–22 years, and over 22 years, and were subjected to statistical analysis. Linear and curvilinear regression equations were formulated separately for each group and

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also for the entire sample together to find out whether a single equation could be used for all age group or independent equation would be required separately for individual age group to estimate stature. Efforts were also made to formulate multiplication factors and to find out any sex differences.

3. Results

A total of 250 cases (125 males and 125 females) (Table 1) were studied for estimation of stature by foot length.

Table 1
Age and sex wise distribution of cases

Age group	Males	Females	Total
Under 20 years	35	57	92
20–22 years	72	61	133
Over 22 years	18	7	25
Total	125	125	250

Table 2
Sex wise distribution of stature

Stature (in cm)	Male ($n = 125$)	Female ($n = 125$)
Mean	173.99	159.56
SD	6.13	6.25
Minimum	156.5	144.9
Maximum	190.9	180.2

Stature: Table 2 shows that stature in males varied from 156.50 cm to 190.90 cm with a mean value of 173.99 and standard deviation was 6.13. The stature in females varied from 144.90 to 180.20 with mean value of 159.56 and standard deviation was 6.25.

The box plots (Fig. 1) are graphical presentations of the data shown in Table 2.

Foot length: Table 3 shows that in the case of males, right foot length varied from 23.30 cm to 29.00 cm with mean value of 26.12 cm and standard deviation was 1.09. Whereas, left foot length varied from 23.1 cm to 29.1 cm with mean value of 26.09 cm and standard deviation was 1.10. In case of females, right foot length varied from 21.1 cm to 26.3 cm with mean value of 23.33 cm and standard deviation was 1.08. The length of left foot varied from 21.2 cm to 26.3 cm with mean value of 23.29 cm and standard deviation was 1.10.

The box plots (Fig. 2 and 3) are graphical presentations of the data shown in Table 3.

Estimation of stature: For estimation of stature, two models such as *Linear Regression* and *Curvilinear Regression* were used, which are as follows:

1. *General multiple linear regression model:* To explain for stature, all the explanatory variables, viz, age, sex, left and right foot lengths, left and right foot breadths were included for model generation using SPSS. The following *general model* came out:

$$\text{Stature} = 67.568 + 3.862\ \text{FLRIGHT} - 3.393\ \text{Sex} + 0.437\ \text{Age} \quad (r = 0.877; R^2 = 0.769)$$

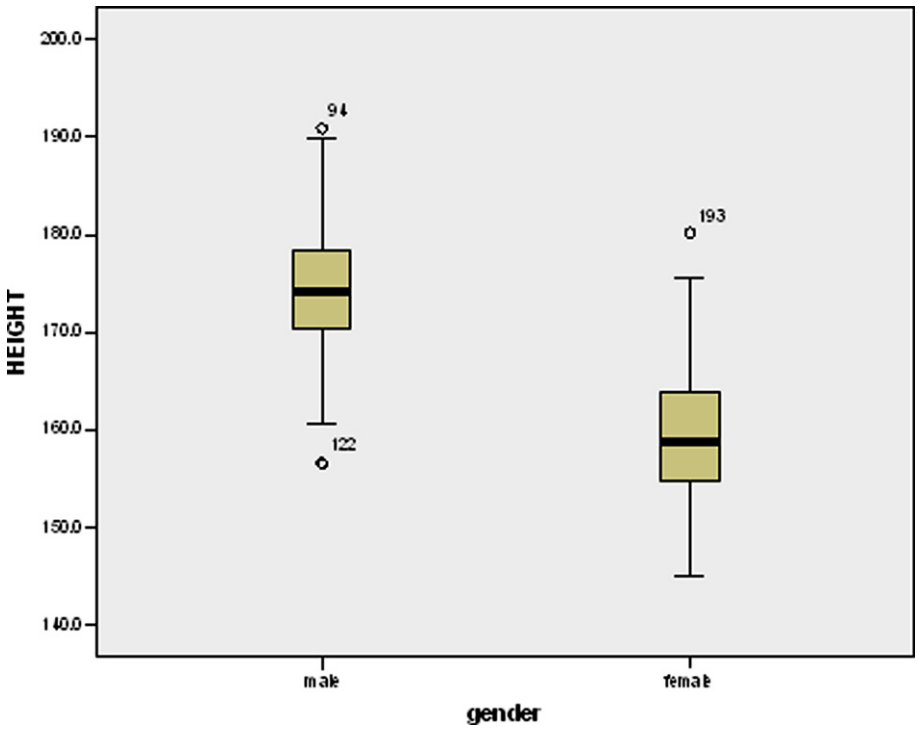

Fig. 1. Box plots – Sex wise distribution of stature.

Table 3
Sex wise distribution of foot length

Foot length (in cm)	Male		Female	
	Right side	Left side	Right side	Left side
Mean	26.12	26.09	23.33	23.29
SD	1.09	1.10	1.08	1.10
Minimum	23.30	23.10	21.10	21.20
Maximum	29.00	29.10	26.30	26.30

That is, right foot length (FLRIGHT), sex and age explain for about 77% variations in stature. This model is highly significant and is validated. (*Note:* In the case of sex, male was coded as '1' and female was coded as '2'.)

2. *Linear regression model per sex category:* To explain for stature per sex the explanatory variables were selected, viz, age, left and right foot lengths, left and right foot breadths. The following models emerged:

(a) Male:

(i) $\text{Stature} = 68.586 + 4.036\ \text{FLRIGHT}$
$(r = 0.720; R^2 = 0.518)$

(ii) $\text{Stature} = 55.695 + 4.417\ \text{FLRIGHT} + 0.489$
$\text{Age} \quad (r = 0.731; R^2 = 0.534)$

Two probable models emerged for males: the first model where height is being explained by right foot length only, and the latter accounting for about 52% variation in stature; the second model where stature is explained by right foot length and age of male students (the addition of age as explanatory model in the model accounting for an increase of only about 2% variation in stature as compared to the first model, as can be observed from the R^2 values). Both regression models are highly significant ($P < 0.01$) as are the predictors in the models ($P < 0.01$).

(b) Female:

$\text{Stature} = 77.059 + 3.536\ \text{FLRIGHT}$
$(r = 0.608; R^2 = 0.370)$

In the case of females, the right foot length again emerged as the principal explanatory variable explaining for about 37% variation in stature. But the regression model is still highly significant ($P < 0.01$) as are the predictors in this model ($P < 0.01$).

3. *Curvilinear model per sex category:*

(a) Male:

$\text{Stature} = 279.023 - 1/2738.461\ \text{FLRIGHT}$
$(R^2 = 0.524)$

(b) Female:

$\text{Stature} = 242.256 - 1/1925.487\ \text{FLRIGHT}$
$(R^2 = 0.369)$

4. *Linear model per age category:* Note that the models for both males and females for each age category, i.e., under 20 years; 20–22 years and over 22 years were not consistent with that of the general models.

4. Discussion

The determination of stature is an important step in the identification of dismembered remains. Anthropometric techniques are commonly used by anthropologists and adopted by medical scientists to estimate body size for the purpose of identification.[2] Many studies have been conducted to determine stature by taking measurements of long bones and various percutaneous body measurements.

Foot length displays a biological correlation with height that suggests the stature might be estimated from foot length.[3] The foot is also useful in the context of identity, as it is protected by the shoe. There are many studies[4–7] in which an attempt has been made to establish correlation between stature and foot dimensions. This study extends the findings of previous studies by exploring data i.e. foot lengths (right and left) and height using linear and curvilinear regression models with and without sex and age indicator. A general multiple linear regression model was found to be most promising and validating which was consistent with the study conducted by Sanli SG et al.[4] This model is highly significant as revealed by ANOVA ($F = 272.78$, $P < 0.001$). *T*-tests reveal the significance of all the predictors: FLRIGHT ($t = 14.429$, $P < 0.001$); Sex ($t = -3.493$; $P < 0.01$); Age ($t = 2.314$, $P < 0.05$) and constant ($t = 7.316$, $P < 0.001$). Among all the groups, a significant correlation was established in regard to stature and right foot length which was similar to the finding observed by Ozden H et al.[5] Linear regression model per sex category explained stature for males by two probable models; the first model where stature was being explained by right foot length only, and the second model where stature was explained by right foot length and age of students. As for the female group, the right foot length only emerged as the principal explanatory variable.

The hypotheses were stated to test for differences in foot lengths between sexes: *Null hypothesis* – there is no difference in foot sizes between the sexes and *alternative hypothesis* – there is a difference in foot sizes between the sexes. The statistical significance threshold level for all inferential tests is $\alpha = 0.05$. A test of normality reveals that all the data for the different foot characteristics are normal ($P > 0.05$). Hence, an independent *t*-test is used to test for the difference between sexes. The *t*-tests for all the four foot characteristics show that the differences between sex are very highly significant ($P < 0.001$); with the average foot sizes of males being significantly greater than for females.

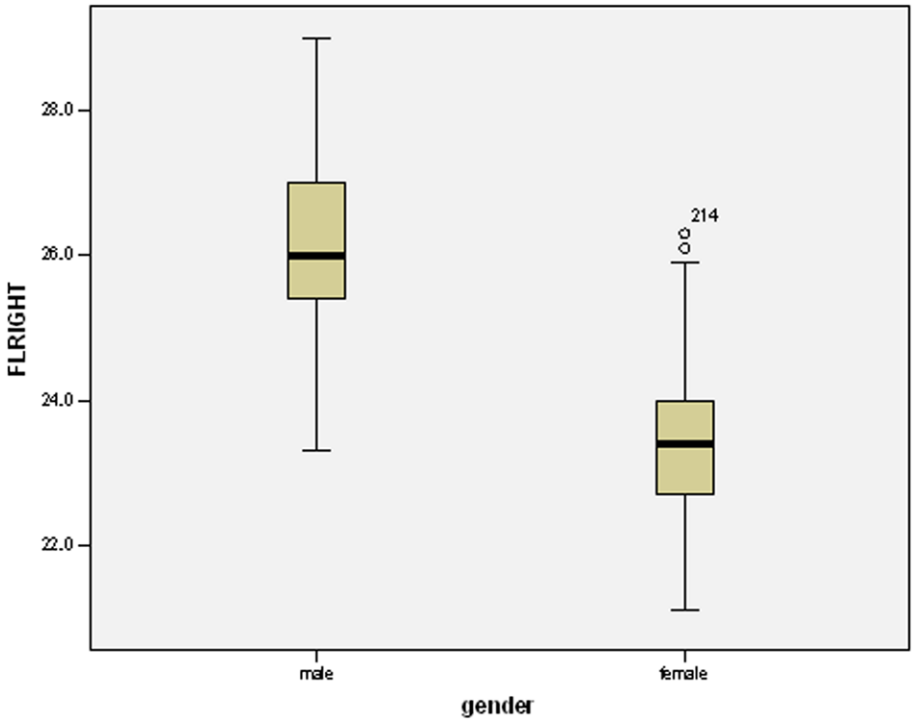

Fig. 2. Box plots – Sex wise distribution of right foot length.

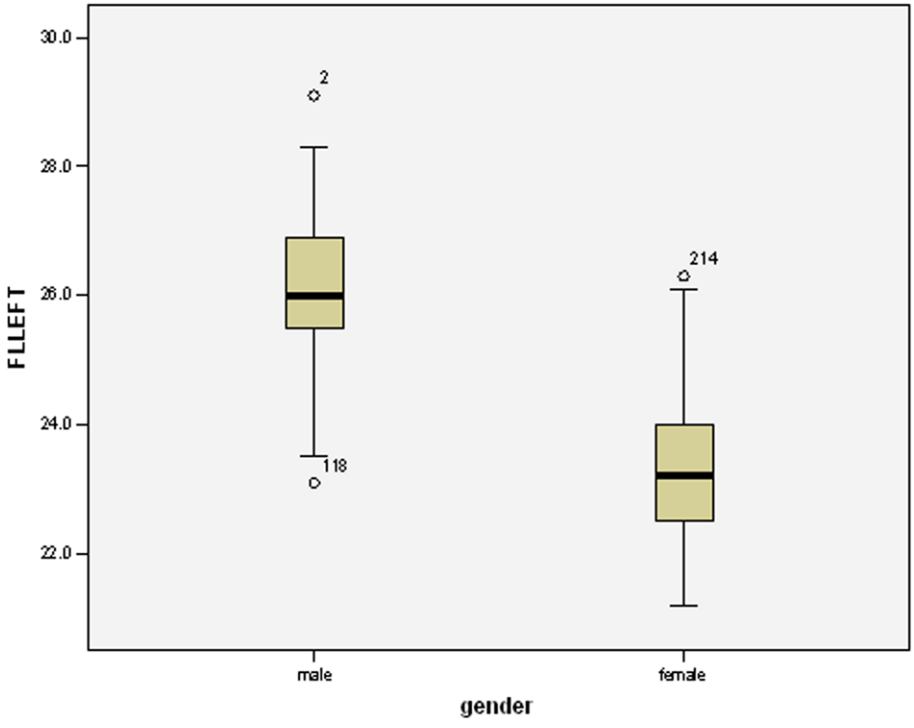

Fig. 3. Box plots – Sex wise distribution of left foot length.

Limitation of study: This study has been conducted on medical students mainly from Mauritius and India. Therefore other studies in different parts of the world are required to confirm whether it would be equally applicable elsewhere.

5. Conclusion

To conclude, it was understood that the foot length is a prime criteria to estimate stature of a person. The results show significant correlations between stature of an individ-

ual and foot length. This equation may be helpful to obtain approximate stature of an individual when there is difficulty in obtaining direct measurement such as in fragmented remains of body (e.g. foot and leg).

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